Internet Resources

Future Human Exploration
http://www-sn.jsc.nasa.gov/explore/explore.htm

Mars Pathfinder
http://mars.jpl.nasa.gov

Mars Global Surveyor
http://mars.jpl.nasa.gov/mgs

Mars Team Online
http://quest.arc.nasa.gov/mars

Lunar and Planetary Institute
http://cass.jsc.nasa.gov

NASA Advanced Life Support Program
http://pet.jsc.nasa.gov/alssee/demo_dir/alspub.html

National Space Science Data Center
http://nssdc.gsfc.nasa.gov/planetary/planets/marspage.html

Lunar Prospector
http://lunar.arc.nasa.gov

Near Earth Asteroid Rendezvous
http://near.jhuapl.edu/

MarsWatch
http://mars.catlin.edu/mpf/marswatch.html

The Martian Chronicle
http://www.jpl.nasa.gov/mars/MartianChronicle/

Romance to Reality: Moon & Mars Expedition and Settlement Plans
http://members.aol.com/dsfportree/explore.htm

Center for Mars Exploration
http://cmex-www.arc.nasa.gov

The Nine Planets
http://www.seds.org/billa/tnp/nineplanets.html

Spacelink
http://spacelink.msfc.nasa.gov

NASA Headquarters
http://www.nasa.gov

Lyndon B. Johnson Space Center
http://www.jsc.nasa.gov

Earth Science & Solar System Exploration Division
http://www-sn.jsc.nasa.gov

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

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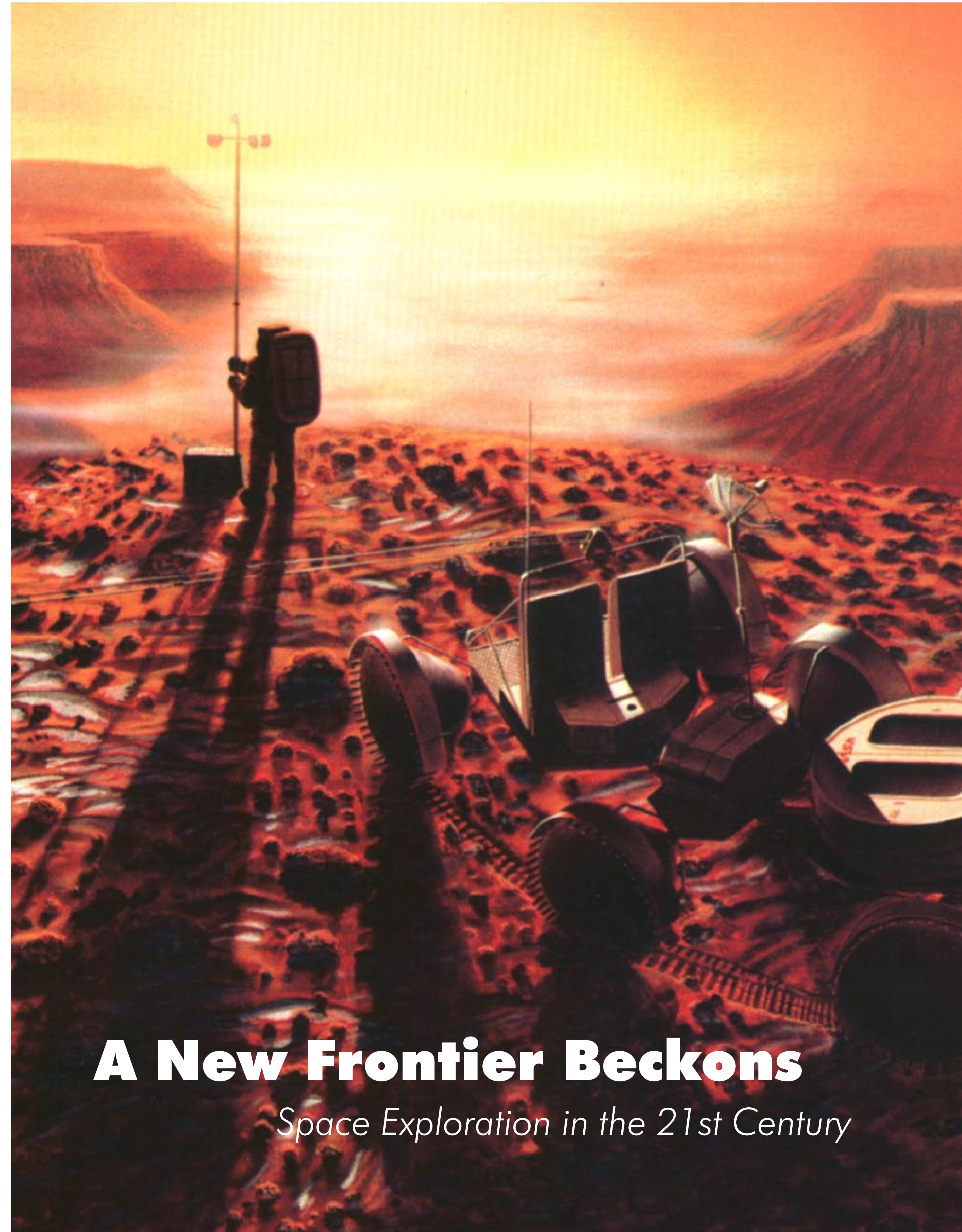


As world history illustrates, humans are compelled to discover new frontiers. Our exploration of the space frontier has already begun. The robotic missions of today and the near future—combined with today's technological advancements—are the first steps toward explorers again venturing beyond low Earth orbit. Human missions back to the Moon and to other destinations in our solar system, such as the planet Mars and near Earth asteroids, will become a reality in the 21st Century, and NASA is leading the way.

Contents

Stunning Announcements

Life on Mars

On August 7, 1996, NASA scientists from the Johnson Space Center stunned the world with news that they believed they had discovered fossilized bacteria in a meteorite that came from Mars. The meteorite, known as ALH84001, and eleven others similar to it have a unique chemistry suggesting they all come from the same place in the solar system. Another one of these meteorites, EETA79001, contained gases which matched those measured by Viking spacecraft that landed on Mars in 1976. Life on another planet! The response around the world was overwhelming. Not only did planetary scientists debate the merits of the claim, but political, religious and social leaders discussed how this discovery impacted our lives and beliefs.

Ice on the Moon

On March 5, 1998, scientists at NASA's Ames Research Center announced that the *Lunar Prospector* spacecraft had detected large amounts of hydrogen near the north and south poles of the Moon, and that this hydrogen was most likely in the form of water ice trapped at the bottom of craters in permanently shadowed areas. Early estimates placed the amount of ice at several hundred million tons, however, recent analyses of the scientific data have raised that estimate to several billion tons! If there, this ice could support a large human presence on the Moon for close to a hundred years by supplying water and oxygen for life support, and oxygen and hydrogen for rocket propellant.

Asteroid 1997 XF11

A week after the *Prospector* announcement the world held its breath when a group of astronomers announced that the mile-wide Asteroid 1997 XF11 would come close to, and possibly hit, the Earth on October 26, 2028. We had just witnessed what the impact of comet Shoemaker-Levy had done to Jupiter, and Hollywood was already promoting two new blockbuster movies about just such an impact on Earth. Luckily, scientists from NASA's Jet Propulsion Laboratory calmed everyone's fears by new calculations showing 1997 XF11 would miss Earth by a "comfortable distance."

> *". . . there is nothing so far removed from us to be beyond our reach or so hidden that we cannot discover it."* **Rene Descartes**

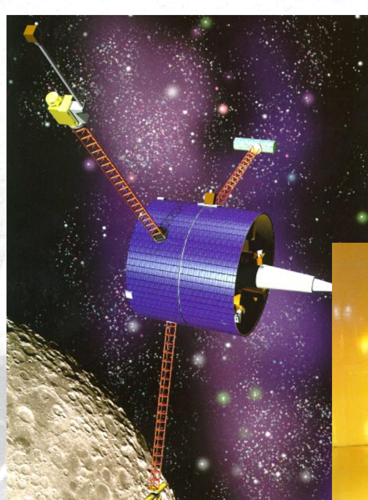
Top: Martian meteorite ALH84001.
Middle: Carbonate rings featuring layered mineral rims and carbonate globules. These carbonate globules were found deep inside meteorite ALH84001. **Inset:** Possible fossilized bacteria found within the carbonate rings using a high resolution scanning electron microscope.
Bottom: Asteroid Ida and its moon, Dactyl.

Robotic Missions Lead the Way

Few people realize that before Neil Armstrong set foot on the lunar surface, NASA sent 19 robotic spacecraft to the Moon to prepare the way. The *Ranger*, *Surveyor*, and *Lunar Orbiter* programs gathered information enabling scientists to characterize the lunar environment and engineers to build spacecraft, space suits, and life support systems to make human exploration possible. Robotic science and human exploration worked hand in hand, resulting in the dramatic and successful Apollo missions. Once again, NASA has a robotic spacecraft in orbit around the Moon, and together with other missions to Mars and the asteroid Eros, our robotic partners in exploration are leading the way for humans to follow.

Lunar Prospector

On January 6, 1998, *Lunar Prospector* was launched from Spaceport Florida's Pad 46 at Cape Canaveral. This is the first spacecraft that NASA has sent to the Moon since the Apollo program. Unlike the Apollo missions that flew above or landed near the lunar equator, *Prospector* is in a polar orbit investigating the entire Moon. While the media and the public have focused their attention on the possibility of water ice at the lunar poles, *Prospector* is also helping answer additional scientific questions about the Moon. What is the chemical composition of the entire lunar surface? What is the Moon's origin and how has it evolved? Are there resources on the Moon that could be used by future human explorers? The answers to these questions will help set the stage for further exploration of the Moon.



Far left: *Lunar Prospector* spacecraft in orbit around the Moon.
Left: *Prospector* being assembled.

Left: *Mars Global Surveyor* launches.
Below: *Mars Global Surveyor* in orbit around Mars.

Mars Global Surveyor

Mars Global Surveyor was launched on November 7, 1996 from Cape Canaveral Air Station in Florida. After reaching Mars in September 1997, *Surveyor* fired its main rocket engine, slowing the spacecraft and allowing the planet's gravity to capture it into orbit. Once in orbit, *Surveyor* began a series of aerobraking manuevers, using the air resistance from the martian atmosphere to slow the spacecraft and lower its orbit. This aerobraking technique will allow the designs of future robotic and human spacecraft to become smaller and less expensive, since large propulsion systems will no longer be needed to decelerate at Mars. Over the course of a full martian year (687 days), *Surveyor* will return scientific data on Mars' atmosphere and weather, surface features and mineral distribution, and the magnetic properties of the planet.

Mars Pathfinder

Mars Pathfinder was also launched from Cape Canaveral on December 4, 1996. On July 4, 1997, *Pathfinder* entered the martian atmosphere and landed on the red planet. This was the first NASA spacecraft to land on Mars since the *Viking* missions in 1976. This mission was primarily an engineering demonstration of key technologies and concepts for eventual use in future missions employing robotic scientific landers. However, science instruments on *Pathfinder* measured the gases in the martian atmosphere, monitored the local weather conditions, and investigated the rocks and soil surrounding the lander. *Sojourner*, a small, solar powered microrover, was driven off the *Pathfinder* lander by scientists at NASA's Jet Propulsion Laboratory in California and was used to conduct further technology experiments and to make chemical analyses of rocks and soil.

Near Earth Asteroid Rendezvous

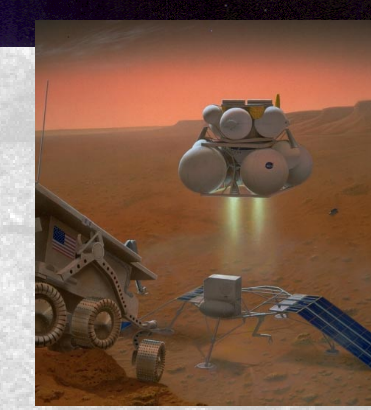
The *Near Earth Asteroid Rendezvous* (NEAR) mission, is the first mission to ever orbit an asteroid. Asteroids are of interest for several reasons. First, some of them may be debris left over from the beginnings of the solar sytem and could contain clues to the earliest processes that shaped the planets, including our Earth. Also, asteroids are the primary source of large bodies that collide with Earth, greatly influencing the evolution of our planet, its atmosphere and life. It is thought that asteroid collisions with Earth have been the cause of several mass extinctions, including the end of the dinosaurs. Finally, asteroid materials, such as nickel-iron metal or water could be used to further human exploration and the development of space. The small target of this mission, asteroid Eros 433, will play a big part in expanding our understanding of the solar syatem.

Future Robotic Missions

Other robotic spacecraft are already being designed and the next series of missions, possibly including sampling ice on the lunar surface or returning rocks or soil from Mars, are in the planning stages. These future missions and the ones described above will enable NASA and the United States to make a decision early in the next century when to begin the new age of human exploration beyond low Earth orbit.

"There are things that are known and things that are unknown; in between is exploration."

Anonymous



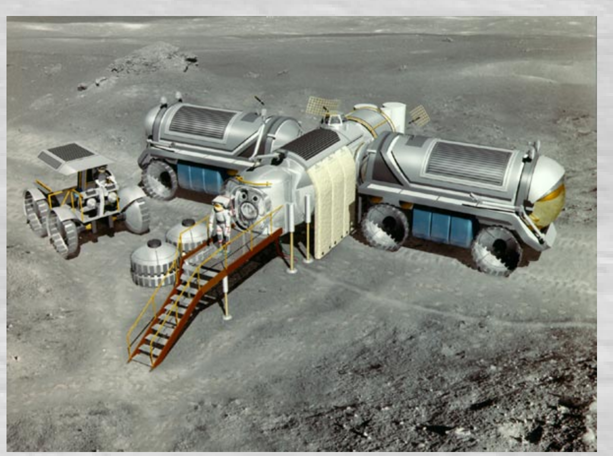
Top: The rover *Sojourner* on Mars next to the rock "Yogi."
Middle: NEAR spacecraft orbiting asteroid, Eros.
Bottom: Mars sample return mission launching samples to orbit.

Humans in Space

While the robotic exploration of the solar system has been mapped out in some detail, the human exploration plan is a work in progress. Currently, NASA's efforts in human space flight are focused on the Space Shuttle and International Space Station programs. Both of these programs are important to the development of a capability for human exploration beyond low Earth orbit. The International Space Station (ISS) will provide extensive research capabilities to determine how the human body reacts to long duration stays in space. The ISS and Shuttle can also provide places for testing equipment or entire systems, such as a habitat module, that could be used on missions to the Moon, Mars, or to a near Earth asteroid. Launch vehicles, which have heritage in Space Shuttle propulsion systems, could deliver the exploration hardware to low Earth orbit and the International Space Station.

Back to the Moon

It has been over 25 years since the Apollo astronauts visited the Moon. Future generations of space explorers will have to relearn how to to work and live on planetary surfaces, and how to do that for months or even years. Since the Moon is less than 5 days away by spacecraft and is readily accessible, the lunar surface has much to offer as a stepping stone into the solar system. Not only could the Moon be used as a testbed for planetary surface operations and equipment, but renewed lunar exploration could address the many scientific questions about the Moon and the Earth-Moon system that remain unanswered.



The Red Planet

Missions to Mars can only be conducted once every 26 months, when the Earth and Mars are in proper alignment. These 'launch windows' are referred to as opportunities. Current NASA plans have cargo missions being sent to Mars first, delivering equipment to the martian surface that will be used by an astronaut crew that arrives 26 months later during the next oppportunity. The spacecraft bound for Mars will be launched from Earth in segments and docked in low Earth orbit. The crew's trip will take 4-6 months depending on the propulsion system used and the alignment of Earth and Mars. As the crew reaches Mars, their spacecraft will enter Mars' atmosphere, much like the Space Shuttle enters Earth's atmosphere, and land near the waiting cargo. Because they have to wait for the next opportunity to return to Earth, the crew will spend approximately 18 months living on and exploring the red planet.

Top: Astronauts explore the Mars surface with their rover.
Left: A small lunar habitat built using pressurized surface rovers.

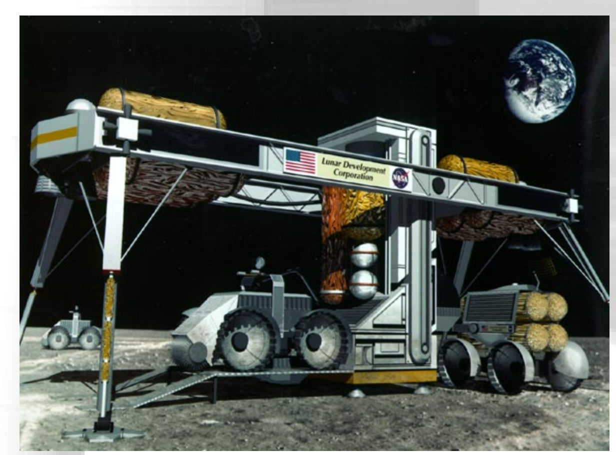
Surface Activities

During their stays on a planetary surface, exploration crews will perform a wide assortment of scientific tasks. On Mars for example, the search for life, past or present, will be a major objective. Other surface activities will include: exploring the area around the oupost, using rovers to collect rock and soil samples; setting up experiments on the surface to monitor the weather, the radiation environment, and any seismic or thermal activity in the planet's interiors; and conducting analyses and experiments inside a habitat laboratory. Of course, the astronauts will also have to spend some of their surface time "doing chores" and maintaining their habitat and other systems.

Living Off the Land

"Living off the land" will characterize humankind's first long term stays on the planets. A whole series of experiments will be conducted using the raw materials of the Moon and Mars to make useful products. For example, equipment could produce rocket propellants for the lander spacecraft by processing the minerals in the local soils, or in the case of Mars, the gases in the atmosphere. Water, or water ice, would be a substantial resource where found. Also, plants could be grown in the local soils to provide food, oxygen, and purified water for the life support systems. Just these initial steps in "living off the land" could reduce the cargo carried to the planets by as much as a third, and show if it is feasible for humans to live on our neigboring planetary surfaces permanently.

"Create ships and sails capable of navigating the celestial atmosphere, then you will find men to man them, men not afraid of the vast emptiness of space." **Johannes Kepler, 1617**



Near Earth Objects

Other possible targets for future human exploration are small asteroids and comet remnants that orbit the Sun in the vicinity of Earth's orbit, collectively called near Earth objects. However, missions to these objects will present the most challenging and hazardous environment for astronaut crews. Like missions to Mars, total mission durations can be up to several years. Protecting the crews from the radiation in space will be one of the primary concerns. Also, because these near Earth objects are so small, the gravity on their surfaces will be minimal. Instead of 'landing' on these objects and conducting surface operations such as roving or walking, missions would more resemble Space Shuttle and International Space Station operations with 'rendezvous and docking' and 'space walks' being the norm.

Top left: Lunar robotic fuel manufacturing station.
Bottom left: Astronauts explore an asteroid from inside their spacecraft.

Building the Technology Foundation Today

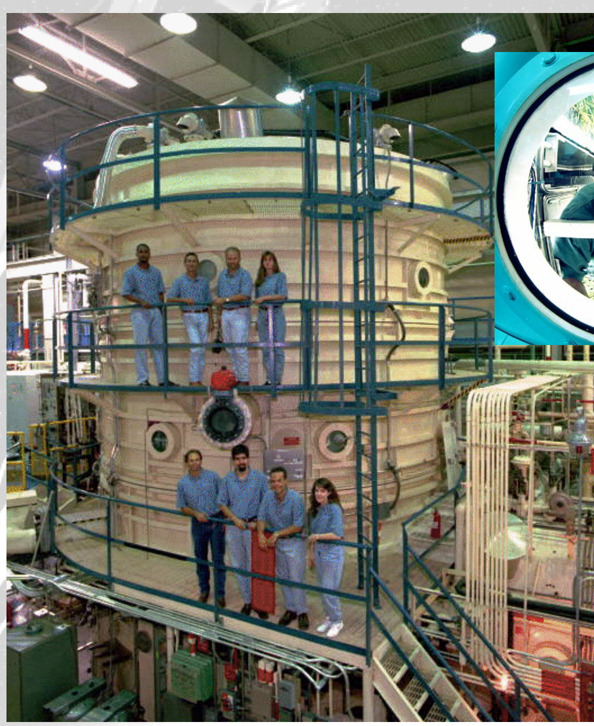
Though human exploration beyond low Earth orbit will not occur until after the International Space Station has been assembled and become operational, engineers and scientists at NASA are hard at work today developing and testing technologies that will be critical for long duration journeys into the solar system.

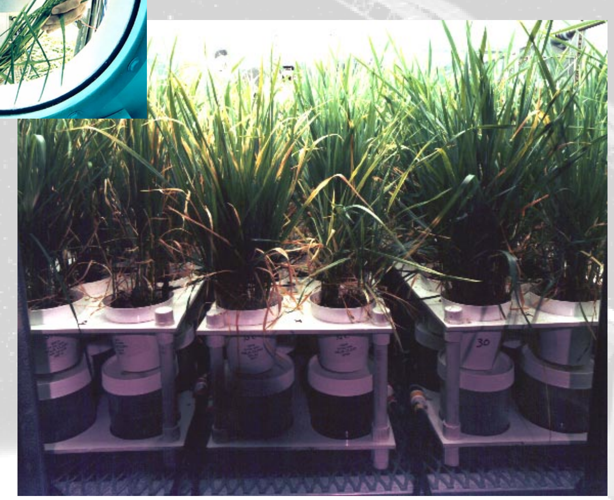
Life Support Systems

The highest priority in a mission beyond low Earth orbit is keeping the astronaut crew safe, healthy, and productive. Life support systems must provide air, water, food, and a liveable environment. For short duration missions of the past (Mercury, Gemini, Apollo) and present (Shuttle) that remain in the vicinity of Earth, "open loop" life support systems provide a fixed amount of consumables (air, food, and water) to be used once. Used water, exhaled carbon dioxide, and human waste are stored away, and as the consumables are used up the mission comes to an end. On long duration missions, this type of life support system will not work. Imagine the amount of space and weight that several years worth of "groceries" would take up! Regenerative, or "closed loop," life support systems are currently being tested. These systems recycle and reuse the air and water, and grow food for the crew. In essence, these systems duplicate what our biosphere on Earth does for us. Test subjects have already lived for months at a time inside sealed chambers, counting on regenerative systems to supplement their air and water. Eventually, these systems could be tested in a space environment on the International Space Station.

Space Resources

As explorers of past eras ventured into new territories, they relied on the natural resources there to sustain themselves and their explorations. The physical constraints of their ships, wagons, sleds, or pack animals made it impossible for them to bring everything that they would need to survive. The amount of resources available in the new lands, and the extent to which those resources could be used, determined whether or not outposts and settlements would follow the explorers into the new frontier. The exploration of the solar system will present similar challenges and opportunities. To meet those challenges, NASA is testing techniques to extract oxygen from the minerals on the lunar surface and the largely carbon dioxide atmosphere of Mars, to acquire water from possible ice deposits in permenantly shadowed regions near the lunar poles and permafrost or liquid reservoirs beneath the martian surface, and to produce rocket propellants from the materials available at the Moon, Mars, or on asteroids. NASA is also developing a mineral-based long lasting fertilizer that could be mixed with the local planetary soils to grow food crops.



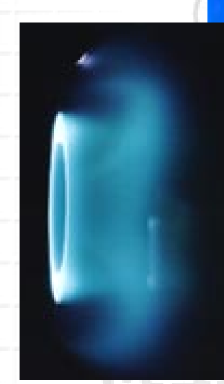


Left: Advanced Life Support Chamber at JSC and some of the people who lived in it. **Center:** Scientist with plants that provided his oxygen. **Below:** Plant growth experiment testing different soils.

Equipment Testing and Engineering

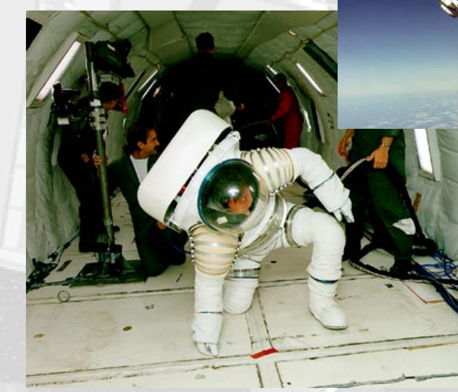
For equipment to work on the Moon, Mars, or on asteroids, it must be designed for and tested in environments similar to those places. NASA has chambers that will serve as planetary environment simulators. In these chambers, the temperatures, surface pressures, atmospheric composition, and dusty environments can all be simulated. Also NASA's KC-135, flown to simulate zero gravity for Space Shuttle astronaut training, can be flown to simulate lunar gravity (roughly 1/6 of Earth's gravity) and martian gravity (roughly 3/8 of Earth's gravity). Thus, equipment such as the new space suits being designed for planetary surfaces will feel right at home when they are eventually used in exploration of the solar system.

The systems and equipment mentioned above are only a few of the many technologies that NASA is developing. Others include, inflatable space structures, remote medical care, and miniaturized sensors and electronics. Even more exotic technologies being tested include ion drive and magnetically contained plasma propulsion systems. These lightweight and efficient rocket engines could revolutionize the way we travel in space.



Above: Ion thruster in cold wall facility at Lewis Research Center.
Left: Ion thruster being test fired.

"Progress is not a leap in the dark, but a succession of logical steps." **Robert Goddard**



Top right: NASA's KC-135 training aircraft can simulate zero gravity and lunar or martian gravity.
Top left: Spacesuit being tested in martian gravity on a KC-135 flight.
Bottom: Spacesuit flexibility and range of motion studies being tested in Arizona.

Summary

Throughout recorded history, small groups of explorers have pushed back the edge of the frontier and opened up new territories for others to follow. As the 20th Century closes, history will record that in the 1960's humankind opened the vast frontier beyond Earth's atmosphere. Although the Apollo program blazed a trail of exploration to the Moon, the development of space has only reached into low Earth orbit. The Space Shuttle and International Space Station programs, and the communication and scientific satellite networks established in orbit around the Earth, are all stepping stones that will enable explorers to venture once again beyond our home planet.

Exploration is difficult. It is difficult for the people and machines that travel in extreme environments and endure harsh conditions, and it is difficult for the national leaders who must champion and fund the programs that lead to discovery and reward.

Left: A human explorer searches for signs of past life on Mars in the year 2020.

Christopher Columbus spent many years meeting with the Kings of Portugal, England, and France only to see his dream of sailing west into the vast Atlantic with ships and crew, discredited. Queen Isabella of Spain was willing to look beyond the many problems plaguing her own shores and see the potential reward for her investment in the future. The voyages of Columbus set the stage for more Spanish explorers, who turned Spain into a great world power.

The Apollo program and the unpiloted *Lunar Orbiter*, *Surveyor*, *Mariner* and *Viking* spacecraft that NASA launched in the 1960's and 1970's were our country's first investment in the exploration of the solar system. These human and robotic missions rewarded us with the first close views of the lunar and martian surfaces, and laid before our eyes territories as vast as all the continents of Earth combined. The *Lunar Prospector*, *Near Earth Asteroid Rendezvous*, and *Mars Pathfinder* and *Global Surveyor* missions are continuing our scientific conquest of the inner solar system, leading the way for humans to follow.

Like the International Space Station program, exploration beyond low Earth orbit will be an international effort. Countries could participate by supplying the many components needed to explore the planets and build permanent outposts. Pressurized habitats, planetary rovers, power systems, robots, and spacecraft could be built in different countries and combined together in Earth orbit, on the Moon, or at Mars. International cooperation will not only spread the risks and costs associated with developing a planetary exploration capability, it will also foster a sense of the world's nations venturing out into the solar system together, for all of humankind.

It is also quite likely there will be opportunities for commercial involvement in the exploration of the solar system. With the privatization of Space Shuttle operations almost complete and similar plans under discussion for the International Space Station, attention is already being focused on how privately owned corporations could participate in planetary operations. Current ideas include: gathering scientific and natural resource data via robotic missions; providing services such as transportation to and from the Moon; providing utilities such as electricity, spacecraft fuel, air and water; developing planetary resources; and building components for planetary outposts, or even entire complexes, and leasing the facilities.

The world's curiosity about the universe, and our solar system in particular, is stronger now than ever before. Spectacular images from the Hubble Space Telescope, the impact of comet Shoemaker-Levy, the success of the Mars Pathfinder mission and the discoveries of possible life on Mars, and ice at the lunar poles are all credited with much of that attention. NASA's mission of exploration beyond low Earth orbit has begun, as we build a foundation of technologies, experience, and scientific knowledge. During the first decades of the 21st Century, explorers from Earth will set foot on other planetary surfaces and expand the human frontier.

Is there life out there in the solar system? Maybe not now, but there will be . . .

"There is nothing more difficult to take in hand, or perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things." **Niccolò Machiavelli**

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